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High Fidelity Topographical Modification of Materials for Lunar Dust Adhesion Mitigation

NASA Lunar Science Institute Forum 2009

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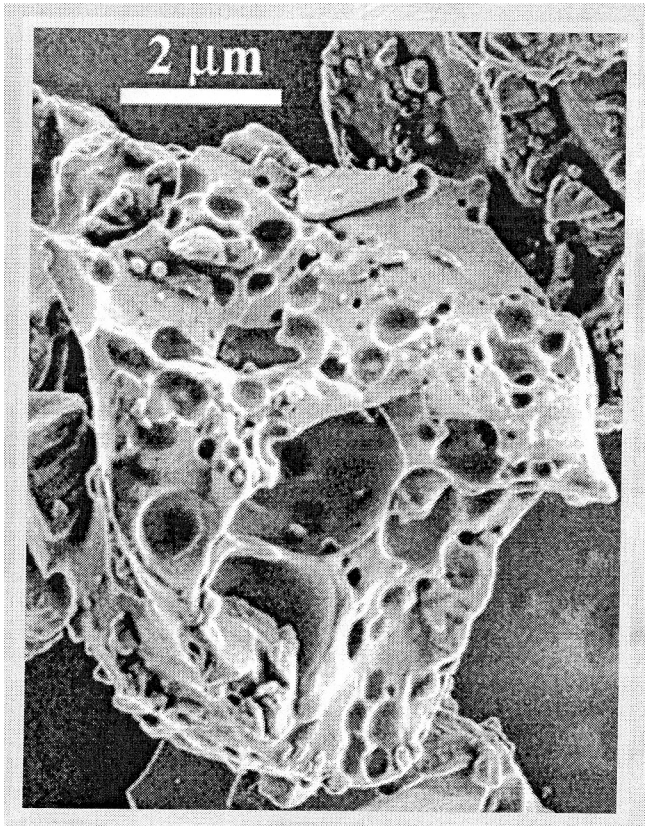
The Lunar Dust Problem … Briefly

The lunar dust is problematic due to its:

- High porosity
- Broad size distribution
- Health risks
- Instrument and equipment compromising capability
- Potentially dynamic state

The lunar dust is ***Strongly Adhesive*** due to:

- Mechanical interlocking
- Electrostatic charging
- Magnetic properties
- Chemical reactivity

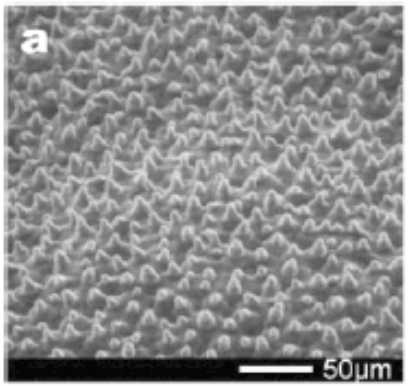


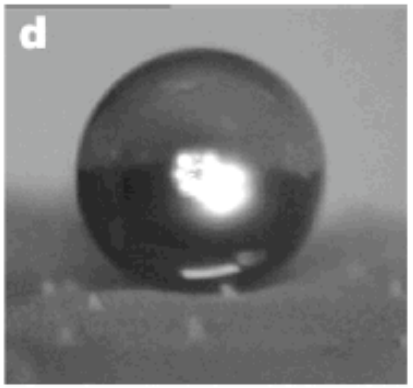
Bell, T., "True-Grit"-Unearthly Dust. *The Bent of Tau Beta Pi* 2006, pp 14 – 16.

Surface Energy vs. Adhesion:
Working Hypothesis

Surface Energy

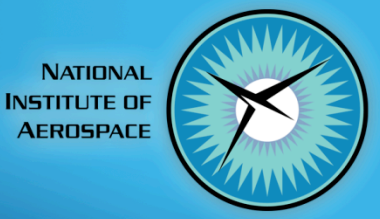
Intrinsic Lunar Dust
Adhesive Interactions





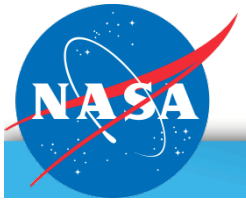
Langmuir **2005**, *21*, 8978.

Lunar Dust Simulant Mitigation Strategies

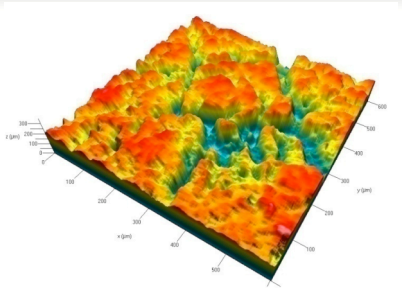


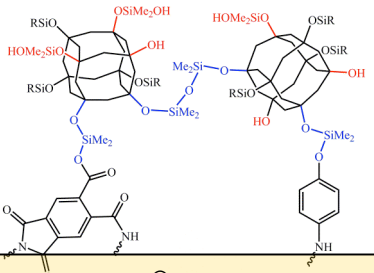
- Objective:
  - Develop a more fundamental understanding of the effects of surface energy and topography on lunar dust simulant adhesion
  - Research surface energy modification methods which are applicable to a diverse array of existing and experimental materials

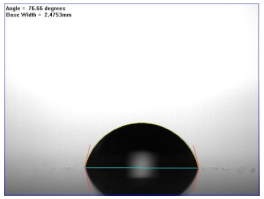
- Approach:
  - Utilize topographical modification techniques and low surface energy materials to introduce lotus-effect surface properties
  - Adhere lunar dust simulant particles to AFM cantilevers and measure the work of adhesion on various surface treatments
  - Evaluate the efficacy of surface treatments for adhesion mitigation through active particle detachment experiments

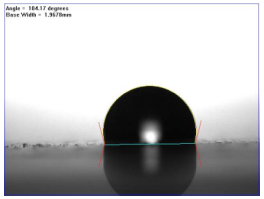


Comparison of Topography Fidelity



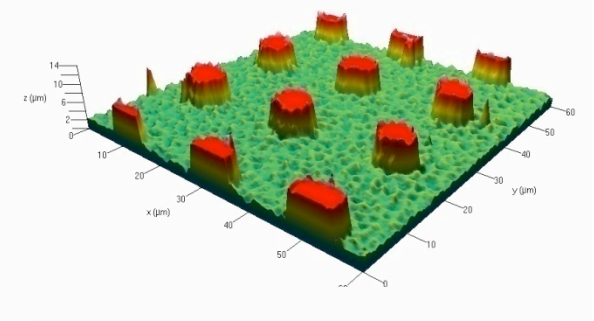


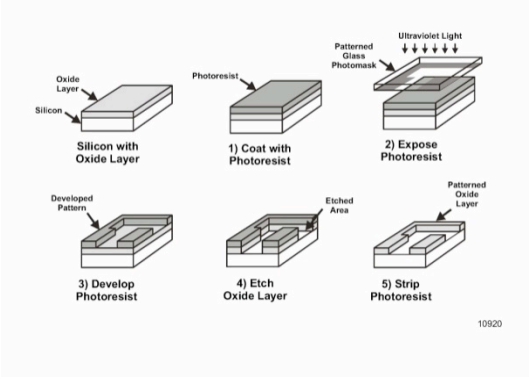




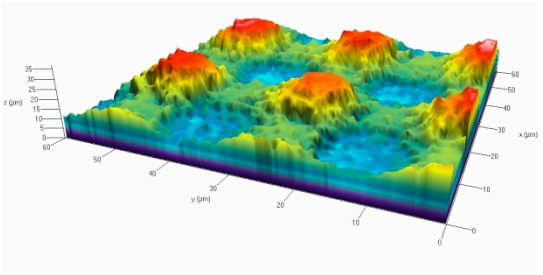
Appl. Surf. Sci. **2009**, *255(18)*, 8135-8144.

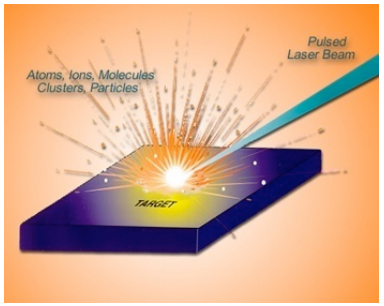
Low Fidelity





Photolithography

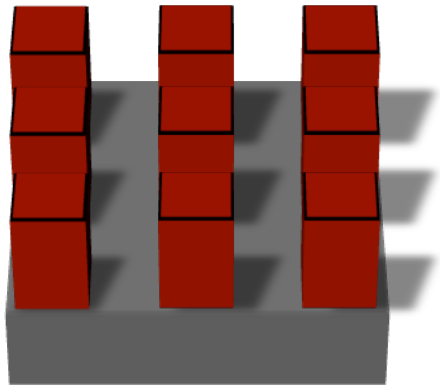




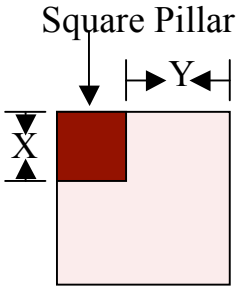
Laser Ablation Patterning

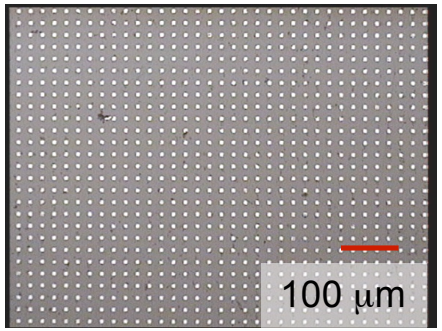
High Fidelity

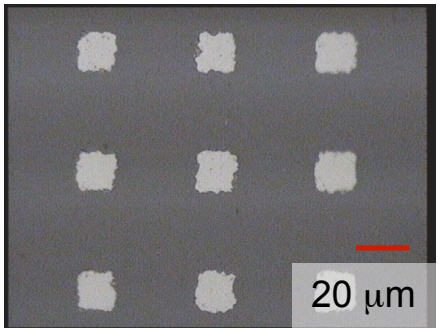
Surface Engineering Question: What Dimensions Should be Used?



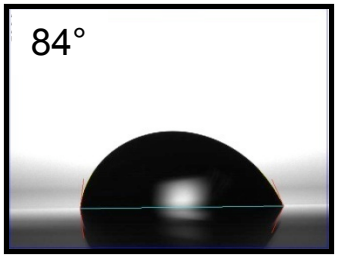
Mask #	Photomask dimensions (mm)		Photomask area (mm^2)		Solid-liquid interface fraction
	X	Y	area	"Pillar" area	
1	20	25	2025	400	0.20
2	20	40	3600	400	0.11
3	20	10	900	400	0.44
4	10	10	400	100	0.25



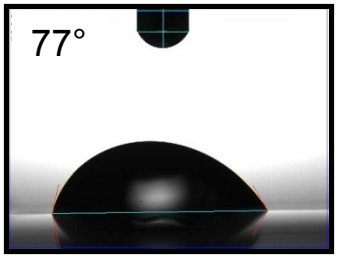




Flat Ni-coated Kapton

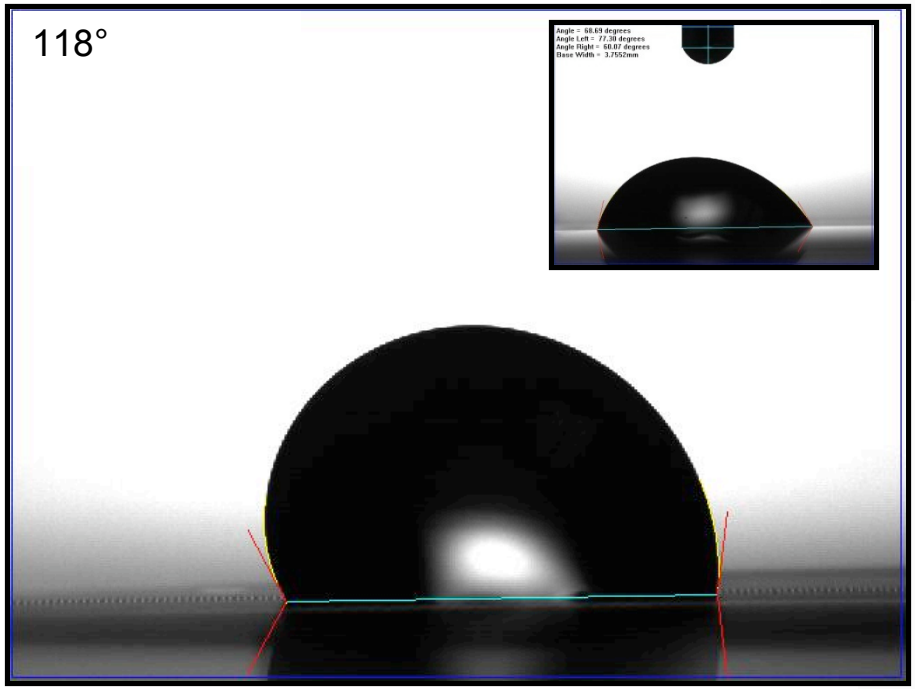


Ni-coated Kapton w/ Photopattern #1

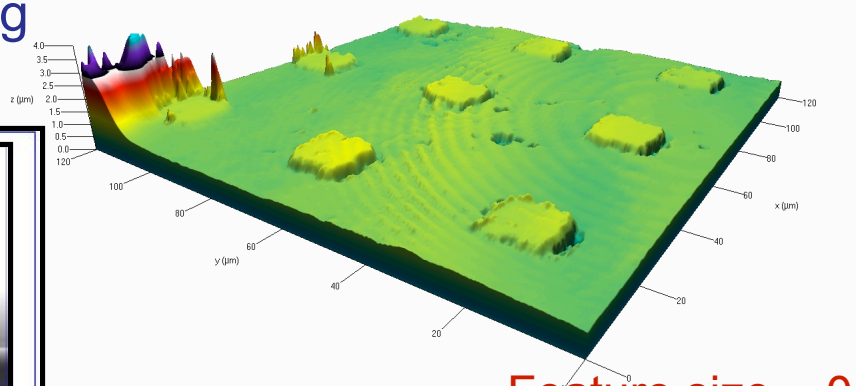


Photolithography Series I:
Ni-coated Kapton®

- Exposure to CF_4 plasma deposits a Teflon®-like layer while increasing the pillar depth

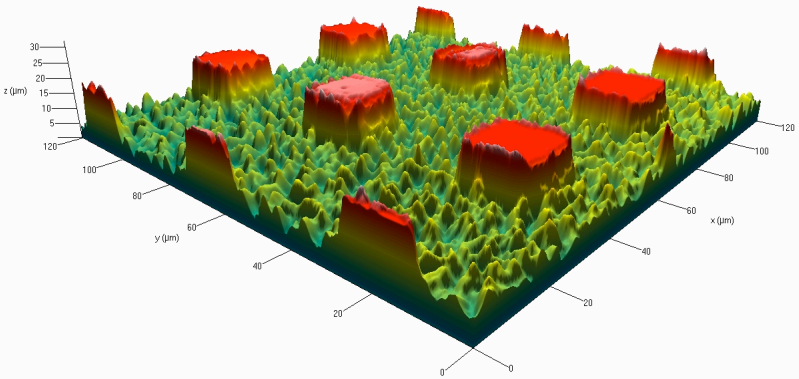


BEFORE



Feature size ~ 0.4 μm

AFTER



Feature size~ 20 μm

Laser Ablation Pattern Visualization: Optical and Confocal Microscopy

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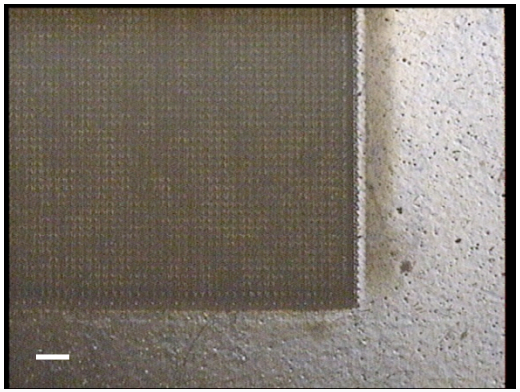
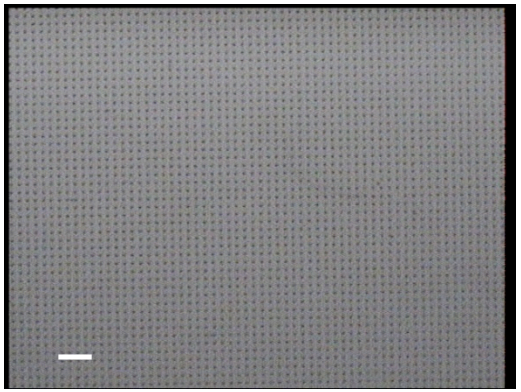
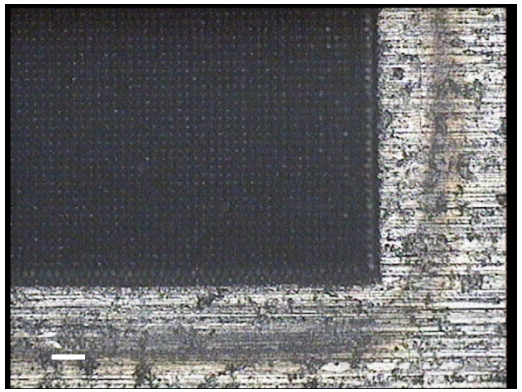
Optical Microscope Images (Scale Bar: 100 μm)



Kapton®

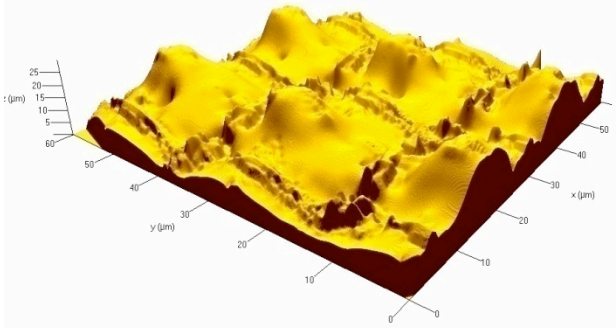


Polyimide Siloxane

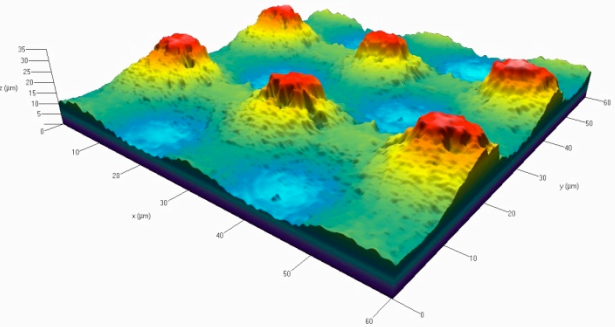


Aluminum 3003H14

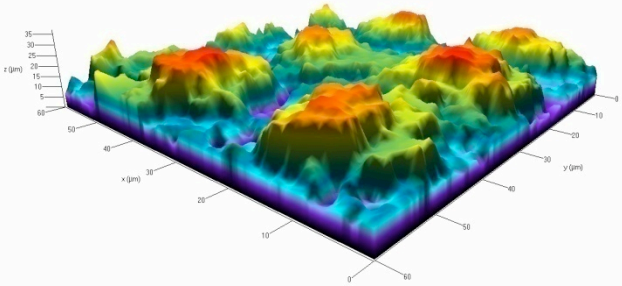
Confocal Microscope Images



15 μm



25 μm



25 μm

Feature sizes

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Laser Ablation of Commercial Materials

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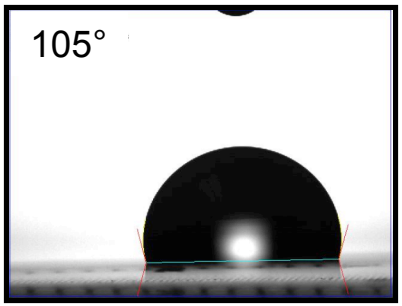
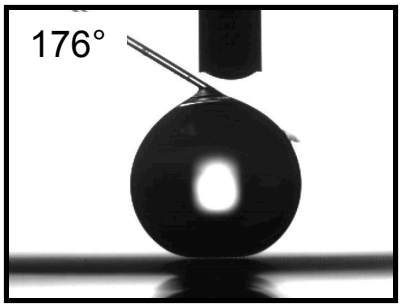
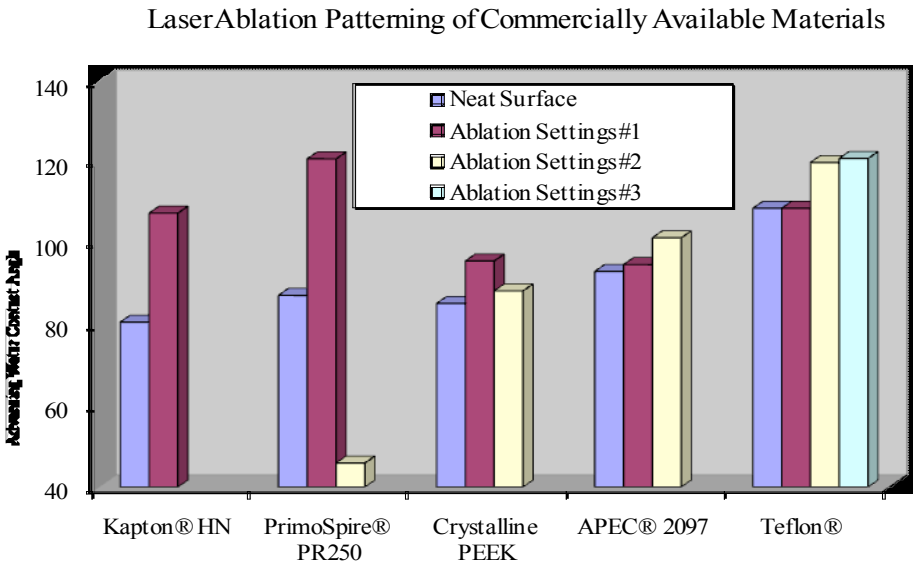
- Laser ablation patterning lowers the surface energy of materials as shown by increasing water contact angles.

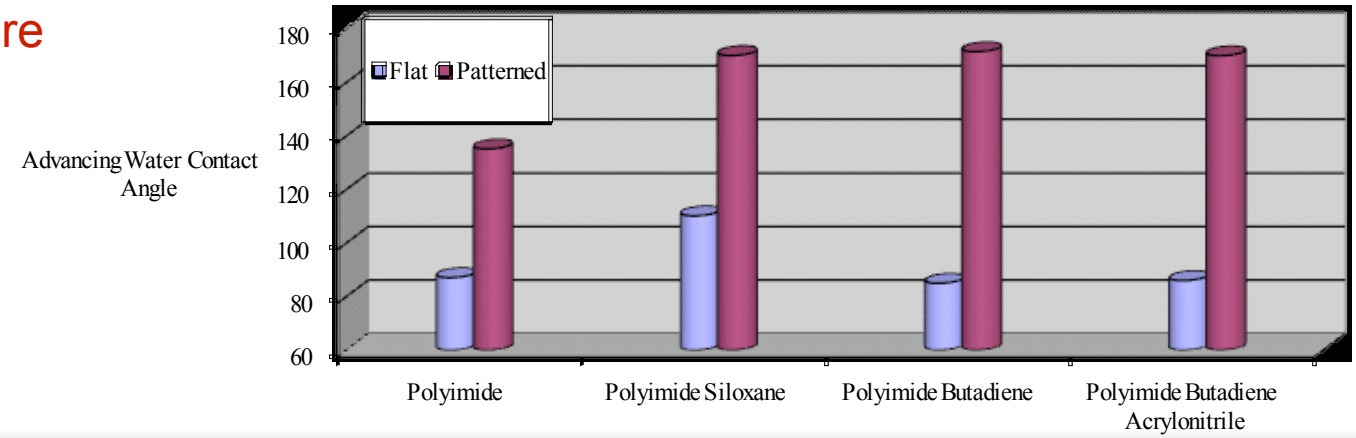


Polyimide Siloxane Before



After





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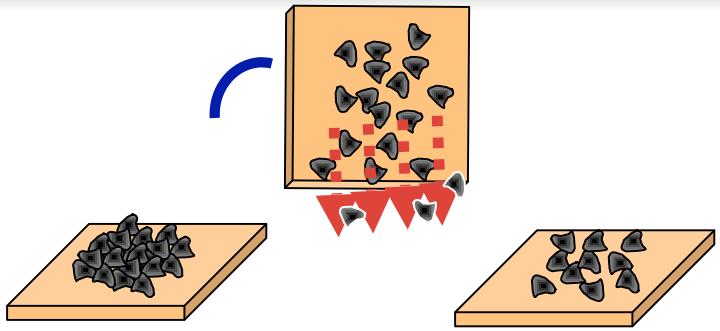
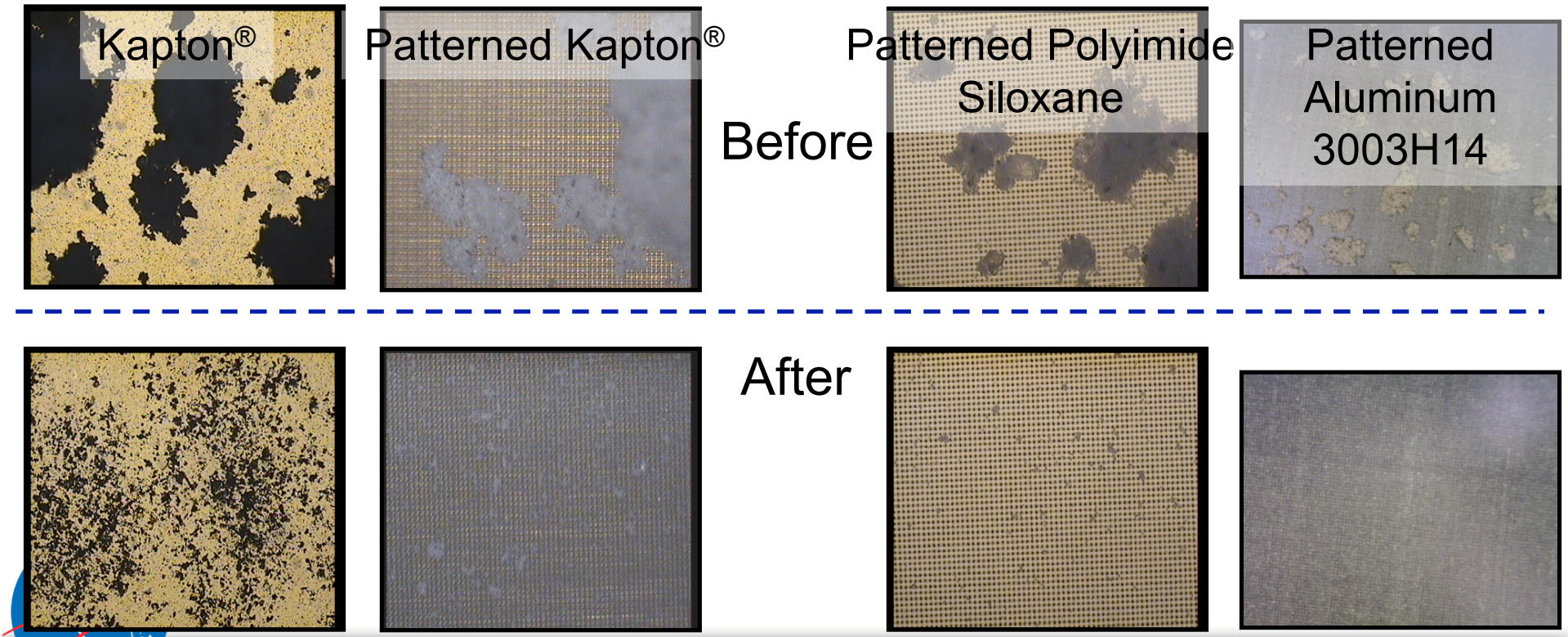
Qualitative Dust Adhesion Testing: Crude Tapping Test

- Lunar dust simulant (≤ 25 μm) was deposited on the surface. The samples were then tilted 90° and tapped once on a hard surface. (50 times magnification)





Dust Adhesion Testing: AFM Adhesion Force Measurement

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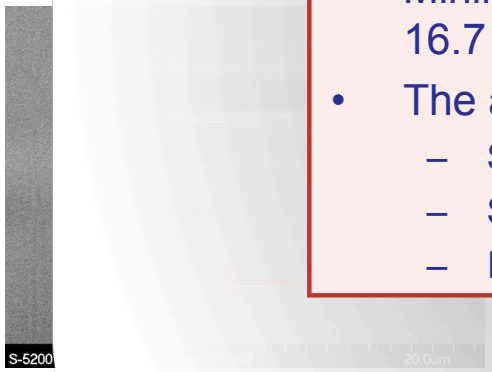
AFM Adhesion Test

Sonic Wand Test

- Largest individual grains ≈ 3 μm
- Spherical particle volume = $4/3\pi r^3$ = 14.2 μm^3
- Particle Mass (SG of 2.9 g/cm^3) = 41 pg
- Surface acceleration was $4.08*10^5$ m/s^2
- Minimal adhesion force for the remaining particles of 16.7 nN.
- The adhesion of:
  - Seasoning to a tortilla chip = 1.6 – 330 nN
  - Silicon nitride AFM tip to tantalum oxynitride = 3 nN
  - ITO-coated AFM tip to CF^3-functionalized Si wafer = 25 nN



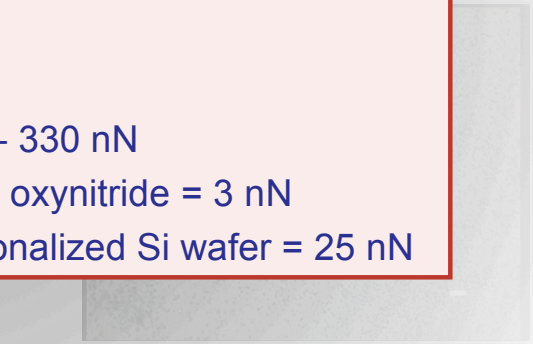


Image Magnified 200 times
Scale Bar = 20 μm

NASA

Conclusions

- No single material, surface preparation, or device will be amenable to every lunar application.
- Surface chemistry and topographical modifications are effective means to tailor materials with specific interfacial properties.
- Laser ablation patterning is a rapid, scalable, high precision technique for engineering surface topographies and is applicable to a wide variety of materials.
- It is important to develop an efficient screening tool towards identifying the efficacy of materials and surface treatments on lunar dust simulant adhesion.
- Our passive approach coupled with active lunar dust mitigation strategies may be advantageous for some applications and is currently under investigation.

Acknowledgements

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John Hopkins

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